PATENT COOPERATION TREATY

REC'D PCT/PTO 25 MAY 2005

From the INTERNATIONAL BUREAU

PCT

To:

DUBUC, J.
Goudreau Gage Dubuc
Stock Exchange Tower
800 Place Victoria, Suite 3400
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Montréal, Quebec, H4Z 1E9
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NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

Date of mailing (day/month/year) 25 February 2004 (25.02.2004)	
Applicant's or agent's file reference JHD/10452.3	**IMPORTANT NOTIFICATION**
International application No. PCT/CA2003/001454	**International filing date** (day/month/year) 23 September 2003 (23.09.2003)

1. The following indications appeared on record concerning:

[X] the applicant [X] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
CONRY, Ronald, David 10 Chipman Point Hudson, Québec J0P 1H0 Canada	AU	CA
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:
The applicant/inventor identified in Box 1 has been removed from the records.

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[ ] the elected Offices concerned
[X] other: CONRY, Ronald, David ;

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer Catherine TOLU (Fax 338-8995)
Facsimile No. (41-22) 338.89.95	Telephone No. (41-22) 338 9958

Form PCT/IB/306 (March 1994)

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference JH0710452.3	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/CA 03/01454	International filing date *(day/month/year)* 23.09.2003	Priority date *(day/month/year)* 25.11.2002
International Patent Classification (IPC) or both national classification and IPC H02P6/24		
Applicant TURBOCOR INC. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 3 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the opinion
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
01.03.2004	24.02.2005
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Braccini, R Telephone No. +49 89 2399-2470

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/CA 03/01454

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

Description, Pages

2-7 as originally filed

Claims, Numbers

1-10 received on 13.12.2004 with letter of 10.12.2004

Drawings, Sheets

1/3-3/3 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)).

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-10
	No:	Claims	
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-10
Industrial applicability (IA)	Yes:	Claims	1-10
	No:	Claims	

2. Citations and explanations

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. The following documents are cited in the international search report:

   D1: US-A-5 574 345 (YONETA TADAO ET AL) 12 November 1996
   D2: EP-A-0 825 702 (SULZER ELECTRONICS AG; LUST ANTRIEBSTECHNIK GMBH (DE)) 25 February 1998
   D3: PATENT ABSTRACTS OF JAPAN vol. 2000, no. 12, 3 January 2001 & JP 2000 257634 A (KOYO SEIKO CO LTD; NIPPON INVERTER KK), 19 September 2000
   D4: BECERRA R C ET AL: "FOUR-QUADRANT BRUSHLESS ECM DRIVE WITH INTEGRATED CURRENT REGULATION" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, IEEE INC. NEW YORK, US, vol. 28, no. 4, 1 July 1992, pages 833-841, XP000306579 ISSN: 0093-9994
   D5: EP-A-0 920 119 (KOLLMORGEN CORP) 2 June 1999
   D6: US-A-5 782 610 (IKEDA HIDEO) 21 July 1998
   D7: US 2002/047402 A1 (MIYAGAWA YASUKATA ET AL) 25 April 2002

2. The application relates to a power control system for an electric motor having a magnetic bearing, in which a rectified DC voltage is provided to a DC/DC converter to generate power supply for a magnetic bearing. During a power failure regenerative electric power from the electric motor (dynamic braking) is provided to the DC/DC converter in order to produce power voltage for the magnetic bearing system.

3. The subject-matter of the independent claim 1 and corresponding method claim 7 lacks an inventive step (Art. 33(3) PCT):

3.1 Document D1 is considered to be the closest prior art in respect of the present claim 1. D1 discloses (the references in parentheses applying to this document):

- A power control system for an electric motor (M) having at least one magnetic bearing (22,26), said system comprising a DC/DC converter (10) supplied from a DC link bus connected to a main power supply (AC input), said bus supplying

power for the electric motor (M) and for a bearing actuator (42), said converter providing low voltage DC power supplies for a motor controller (4,41), a bearing controller (42) and a supervisory controller (11), the supervisory controller (11) monitoring the main power supply and communicating with the motor controller and bearing controller so as to cause the motor to operate as a generator in the event of a failure of the main power supply to thereby supply power to the DC link bus to maintain operation of the magnetic bearing, wherein circuit switching components are connected to the motor winding and selectively switched in a manner causing current generated in the motor winding to flow in one direction into said DC link bus only while the winding voltage is greater than that of the DC link bus (dynamic braking).

3.2 The device of claim 1 differs from this prior art in the following features:

i) D1 fails to mention that the inverter bridge switches are of the IGBT type and that they are controlled according to the rotor position (i.e. the motor is a synchronous machine);

ii) D1 fails to mention the details of the dynamic braking phase, namely that, in case of an AC failure or of a voltage drop in the DC link bus, all bridge switches are turned off and the winding current flows through the corresponding antiparallel diodes to the DC link bus. Thereafter two switches of the bridge are switched on to short circuit a motor winding and are switched off again as soon as the winding current has reached a predetermined magnitude.

3.3 The problem to be solved by the present claim 1 over the prior art is therefore regarded as being to provide an alternative stopping procedure for a magnetic bearing system according to D1.

3.4 The feature (i) defines merely a standard design option which comes within the scope of the customary practice followed by persons skilled in the art (see, e.g. document D5). Hence, feature (i) does not contribute to the objective solved problem (problem/solution approach) and is therefore disregarded for the sake of assessing the inventive step.

3.5 The dynamic braking according to the feature (ii) has already been employed for the same purpose in many similar synchronous machines (see any of documents D4, D5

or D6). It would be obvious to the person skilled in the art, namely when the same result is to be achieved, to apply this feature with corresponding effect to an electric motor with a magnetic bearing according to document D1, thereby arriving at a power control system according to claim 1.
Consequently, the subject-matter of claims 1 and 7 does not involve an inventive step (Art. 33(3) PCT).

4. Dependent claims 2 to 6 and 8 to 10 do not contain any features which, in combination with the features of any claim to which it/they refer, meet the requirements of the PCT in respect of novelty or inventive step (Art. 33(2) and 33(3) PCT), see, e.g. document D5 or D6 and the corresponding passages cited in the search report.

5. The industrial applicability (Art. 33(4) PCT) in view of the cited documents is obviously given for the subject-matter of all claims.

CLAIMS

1. A power control system for an electric motor having at least one magnetic bearing, said system comprising:

a main power supply;

a DC link bus connected to said main power supply, said bus supplying power for the electric motor and for a bearing actuator;

a motor controller;

a bearing controller;

a supervisory controller;

a DC/DC converter supplied from said DC link bus, said DC/DC converter providing low voltage DC power supply for said motor controller, said bearing controller and said supervisory controller;

said supervisory controller receiving signals from an AC power monitor and a capacitor connected across said DC link bus, said supervisory controller then signaling said motor controller, said motor controller controlling IGBT switches connecting motor winding to the DC link bus in accordance with a position of a rotor of the motor; each switch having a parallel diode of a polarity opposing a motor current flow during normal operation of said main power supply;

wherein, in one of: signals of failure from the AC power monitor and of: a drop in a voltage across said capacitor, all switches are turned off and an existing current in the motor winding flows through corresponding diodes to the DC link bus, thereby providing an immediate boost to a voltage of the DC link bus; when the DC link bus voltage drops, two switches are closed to short circuit the motor winding and immediately initiate flow of a current therethrough; and as soon as the current flow reaches a predetermined magnitude, the switches are turned off, whereby a winding voltage rises to above the bus voltage and a generated current is pumped back to the capacitor.

2. The power control system as defined in claim 1, said switches being selectively switched to cause the current generated in the motor winding to flow in one direction into said DC link bus only while the winding voltage is greater than the voltage of the DC link bus.

3. The power control system as defined in any one of claims 1 and 2, said switches comprising a first and a second switches connected between a first end of the motor winding and positive and negative sides of said DC link bus respectively; a third and a fourth switches connected between a second end of the motor winding and the positive and negative sides of said DC link bus respectively; a parallel diode being connected across each switch to oppose a normal motor current flow.

4. The power control system as defined in 3, wherein either said first and third or said second and fourth switches are turned on to generate the current in the motor winding, and immediately when a desired current is generated said switches are turned off, whereby the winding voltage rises above the DC link bus voltage and the current flows into the DC link bus.

5. The power control system as defined in 4, said switches being opened when the power failure is detected so that the existing motor current flows through corresponding diodes and into the DC link bus to boost the DC link bus voltage, and when said DC link bus voltage drops, either said first and third, or said second and fourth switches are closed to short circuit the motor winding and immediately initiate current flow therethrough, whereupon said switches are opened causing the winding voltage to rise above the DC link bus voltage, the generated current being fed back to the DC link bus.

6. The power control system as defined in 5, the voltage across the dc link bus being determined by a capacitor connected between the positive and negative sides of the DC link bus, said connector storing power fed back from the winding for motor run down.

7. A method of running down a high speed DC electric motor run on magnetic bearings in an event of a failure of a main power supply thereof, including the steps of:

supplying the motor and the magnetic bearings from a high voltage DC bus connected to the main power supply;

providing a DC/DC converter to supply low voltage DC power to a magnetic bearing controller and to a motor controller, using switching devices to control a motor operation;

sensing a failure of the main power supply and providing a signal to the motor controller; and

selectively controlling the switching devices;

said step of selectively controlling the switching devices comprising initially feeding an existing motor current to the DC bus, detecting when a voltage of the DC bus drops below a predetermined value, shorting windings of the motor, and as soon as a current flow in the motor winding reaches a predetermined magnitude, canceling said shorting of the windings of the motor, whereby the windings voltage rises to above the voltage of the DC bus; feeding a resulting generated current back to the DC bus;

said step of selectively controlling the switching devices being repeating until the motor is run down.

8. The method according to 7, further comprising the steps of connecting a capacitor across the DC bus and of providing an AC power monitor for the main power supply, said step of sensing a failure of the main

power supply comprising one of: sensing a voltage drop across the capacitor and of: the AC power monitor emitting a power failure signal.

9. The method according to claim 7, said step of detecting when the bus voltage drops below a predetermined value comprising measuring an indicator voltage by means of a voltage sensor.

10. The method according to any one of claims 8 to 9, the switching devices comprising IGBT switches connected between each end of the motor winding and positive and negative side of the DC bus respectively, a diode being connected in parallel with each switch, the diodes enabling the motor to act as a generator and feed current into the DC bus to assist the capacitor in maintaining the bus voltage until the motor is run down.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 03/01454

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02P6/24 H02J9/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02P H02J H02K H02M F16C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 574 345 A (YONETA TADAO ET AL) 12 November 1996 (1996-11-12) abstract column 3, line 36 -column 4, line 54; figures 2-4	1-9
X	EP 0 825 702 A (SULZER ELECTRONICS AG ;LUST ANTRIEBSTECHNIK GMBH (DE)) 25 February 1998 (1998-02-25) column 1, line 3 -column 4, line 3; figure 1	1-9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2003	05/01/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Braccini, R

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 12, 3 January 2001 (2001-01-03) & JP 2000 257634 A (KOYO SEIKO CO LTD;NIPPON INVERTER KK), 19 September 2000 (2000-09-19) abstract	1-9
A	BECERRA R C ET AL: "FOUR-QUADRANT BRUSHLESS ECM DRIVE WITH INTEGRATED CURRENT REGULATION" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, IEEE INC. NEW YORK, US, vol. 28, no. 4, 1 July 1992 (1992-07-01), pages 833-841, XP000306579 ISSN: 0093-9994 the whole document	1-9
A	EP 0 920 119 A (KOLLMORGEN CORP) 2 June 1999 (1999-06-02) the whole document	1-9
A	US 5 782 610 A (IKEDA HIDEO) 21 July 1998 (1998-07-21) abstract; figure 1	1-9
A	US 2002/047402 A1 (MIYAGAWA YASUKATA ET AL) 25 April 2002 (2002-04-25) the whole document	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 03/01454

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5574345	A	12-11-1996	JP	7238929 A	12-09-1995
			DE	19506849 A1	31-08-1995
			KR	260665 B1	01-07-2000
EP 0825702	A	25-02-1998	EP	0825702 A1	25-02-1998
			DE	59706479 D1	04-04-2002
			US	5917297 A	29-06-1999
JP 2000257634	A	19-09-2000	NONE		
EP 0920119	A	02-06-1999	US	6118241 A	12-09-2000
			EP	0920119 A1	02-06-1999
			IL	125973 A	31-10-2001
			JP	11178389 A	02-07-1999
US 5782610	A	21-07-1998	JP	9163791 A	20-06-1997
US 2002047402	A1	25-04-2002	JP	2002013532 A	18-01-2002

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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10 June 2004 (10.06.2004)

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(30) Priority Data:
2002952885 25 November 2002 (25.11.2002) AU

(71) Applicant *(for all designated States except US)*: TURBO-COR INC. [CA/CA]; 1850 Trans-Canada Highway, Dorval, Quebec H9P 2N4 (CA).

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(74) Agents: DUBUC, J. et al.; Goudreau Gage Dubuc, Stock Exchange Tower, 800 Place Victoria, Suite 3400, P.O. Box 242, Montréal, Quebec, H4Z 1E9 (CA).

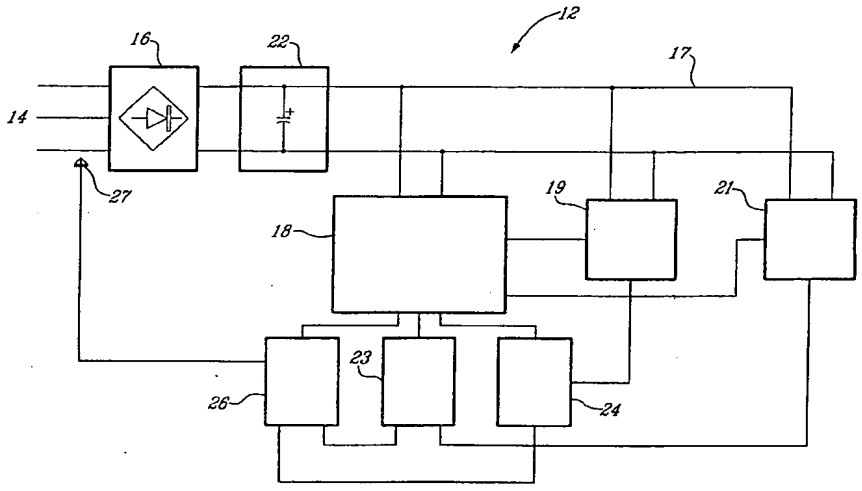
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: POWER SUPPLY CIRCUIT OF A HIGH SPEED ELECTRIC MOTOR



(57) Abstract: A power control system (12) for an electric motor having at least one magnetic bearing includes a DC/DC converter (18) supplied from a DC link bus (179) connected to a main power supply (14), the bus (17) supplying power for the electric motor and for a bearing actuator; the converter (18) provides low voltage DC power supplies for a motor controller (23), a bearing controller (24) and a supervisory controller (26), the later monitoring the main power supply and communicating with the motor controller (23) and bearing controller (24) so as to cause the motor to operate as a generator in the event of a failure of the main power supply (14) to thereby supply power to the DC link bus (17) to maintain operation of the magnetic bearing. Circuit switching components are connected to the motor winding and selectively switched in a manner causing current generated in the motor winding to flow in one direction into the DC link bus (17) only while the winding voltage is greater than that of the DC link bus (17).

WO 2004/049551 A1

POWER SUPPLY CIRCUIT OF A HIGH SPEED ELECTRIC MOTOR

Field of the Invention

This invention relates to a power supply for a high speed electric motor and relates particularly to a power supply for a motor using magnetic bearings.

International Patent Application No. WO 98/33260 describes a high speed electric motor which is particularly suitable for use as a refrigeration compressor motor. Such a motor may be used in, for example, a compressor of the type described in Australian Patent No 686174 and utilizing magnetic bearings for the suspension of rotating parts.

Background of the Invention

A known difficulty with the use of magnetic bearings is to supply power to the bearings during a system power failure, during which the power supply to the motor fails. While it is known to use auxiliary or back-up power supplies to the system, such as by way of batteries or the like, such auxiliary power supplies are relatively expensive and require additional switching controls to enable the auxiliary supply to take over when the main power supply fails. Further, the batteries have a limited life and generally must be replaced every two (2) years. This adds substantial further costs to the system.

It is therefore desirable to provide an improved power supply system for a high speed electric motor running in magnetic bearings which can maintain power to the bearings in the event of a main power supply failure.

It is also desirable to provide a power supply system for continuously supplying power to the magnetic bearings of a high speed electric motor following a failure of the main power supply until such time as the rotating parts are at rest.

It is also desirable to provide an improved controller for a high speed electric motor which enables a spinning rotor to spin down under controlled conditions.

It is also desirable to provide a power supply controller for a high speed electric motor with magnetic bearings which is relatively inexpensive, which is efficient in its operation and which provides a substantially fail-safe power supply for the magnetic bearings.

Summary of the invention

In accordance with one aspect of the invention there is provided a power control system for an electric motor having at least one magnetic bearing, said system comprising a DC/DC converter supplied from a DC link buss connected to a main power supply, said buss supplying power for the electric motor and for a bearing actuator, said converter providing low voltage DC power supplies for a motor controller, a bearing controller and a supervisory controller, the supervisory controller monitoring the main power supply and communicating with the motor controller and bearing controller so as to cause the motor to operate as a generator in the event of a failure of the main power supply to thereby supply power to the DC link buss to maintain operation of the magnetic bearing characterised in that, circuit switching components are connected to the motor winding and selectively switched in a manner causing current generated in the motor winding to flow in one direction into said DC link buss only while the winding voltage is greater than that of the DC link buss.

The invention is preferably adapted for use with a high speed electric motor, the rotor of which is supported solely by magnetic bearings. The invention may also be utilised for an electric motor having a combination of magnetic and gas bearings.

Preferably, the DC link buss incorporates at least one capacitor, which, in normal use, is maintained in a charged condition by the main power supply. The capacitor is able to provide sufficient power in conjunction with that supplied by the motor running as a generator to run down the motor from full speed and maintain operation of the magnetic bearings during the run down period. Running the motor as a generator during the run down period extracts the kinetic energy stored in the motor and other rotating parts and constitutes an electric brake to quickly and safely stop the rotor rotation. During the run down period, power continues to be supplied from the motor, running as a generator, to the DC link buss which provides an uninterruptable power supply to the DC/DC converter and the several controllers as well as the magnetic bearing actuator for the full run down period.

In accordance with another aspect of the invention there is provided a method of running down a high speed DC electric motor run on magnetic bearings

in the event of a failure of the main power supply, said method including the steps of supplying the motor and the magnetic bearings from a high voltage DC buss connected to the main power supply, proving a DC/DC converter to supply low voltage DC power to a magnetic bearing controller and to a motor controller, using switching devices to control the motor operation, sensing a failure of said main power supply and providing a signal to the motor controller, characterized in that, said switching devices are selectively controlled on sensing said failure, to initially feed existing motor current to said buss, detecting when said buss voltage drops below a predetermined value and shorting said motor winding, and as soon as current flow in said winding commences, as a result of the short, removing said short whereby the winding voltage rises to above the buss voltage, feeding the resulting generated current back to said buss, and repeating said selective control as necessary until said motor is run down.

According to one embodiment of the invention the power control system incorporates a plurality of switches operable to switch power between the two polarities of the DC buss and each end of the motor winding to switch the current flow through the winding. Each switch has a diode in parallel. When a mains power failure is sensed, such as by measuring a voltage drop across the buss, the switches are all switched to the "off" position and current existing in the motor coil is fed to the buss. As soon as the buss voltage drops again, the motor winding is shorted by closing the appropriate switches and then opened to let the current, generated by shorting the winding, be pumped back into the buss through the diodes.

This control method uses the existing motor control IGBT switches to realise the generator function of the motor when the buss voltage falls. With this control system, there is no need to track the rotor position and control switching as a function of rotor position. The diodes enable the motor to act as a generator with all switches in the open position and the current being pumped into the buss to assist the installed capacitor for maintaining the buss voltage until the motor is run down.

One embodiment of the invention will now be described with reference to the accompanying drawing wherein:

Figure 1 is a block diagram of a power control system in accordance with the present invention;

Figure 2 is a schematic circuit diagram illustrating the control switches for a single phase motor and

Figure 3 is a flow chart of the control algorithm of the system shown in Figures 1 and 2.

Description of one embodiment

Referring to the drawings and firstly Figure 1, the power control system 12 is connected to a three phase AC power supply 14 through a bridge rectifier 16. A DC link buss 17 supplies DC power to a DC/DC converter 18, magnetic bearing actuator 19 and electric motor power supply 21. A large capacitor 22 or capacitor bank is connected across the link buss 17 to provide a buffer of stored power for motor run down. In this embodiment, the DC link buss voltage is 1000V and the capacitor, or several capacitors, will have a capacity sufficient for a motor run down time of about 0.1 sec to about 1.5 sec, in the absence of any other power source.

The DC/DC converter 18 provides low voltage DC power for a motor controller 23, a bearing controller 24 and a supervisory controller, which, in this embodiment, takes the form of a computer 26. The converter 18 also supplies low voltage power for various sensors associated with the magnetic bearings and for Insulated Gage Bipolar Transistors (IGBT) (not shown) which are used for control purposes in the magnetic bearing actuator 19 and the electric motor power supply 21. The magnetic bearing actuator 19 and associated IGBTs and the electric motor power supply 21 and its associated IGBTs are known in the art and will not be described in detail. Gate drive signals for the various IGBTs are generated by the bearing controller 24 and motor controller 23, respectively, to provide the desired operational parameters for the electric motor bearings.

An AC power monitor 27 provides a signal to the supervisory computer 26 in the event of a failure of the main AC power supply 14. Alternatively, the supervisory computer 26 may monitor the buss voltage, through DC/DC converter 18, to detect a power failure which results in a voltage drop across the capacitor 22. On detection of a power failure, the motor controller 23 controls the IGBTs to feed

existing motor current to the DC link buss and to then open whereby motor winding current reverses relative to the motor magnetic field thereby turning the electric motor into a generator.

Referring to Figure 2, the IGBT switches 28, which are controlled by the motor 23, connect motor winding 29 to the DC buss 17 in accordance with the rotor position. While four switches 28 are shown in Figure 2, in a three phase motor structure, six switches 28 will be provided.

Each switch 28 has a parallel diode 31 the polarity of which opposes the motor current flow. When a power failure is detected either by power monitor 27 or by detecting a voltage drop across the capacitor 22, all switches are turned off, or opened, and existing current in the motor winding 29 flows through the relevant diodes 31 to the buss 17. This provides an immediate boost to the buss voltage, and as soon as the buss voltage again drops, two switches SW1 and SW3 or SW2 and SW4 are closed to short circuit the motor winding 29 and immediately initiate flow of current therethrough. As soon as the current flow commences as a result of the short, the switches are again turned off whereby the winding voltage rises to above the buss voltage and generated current is pumped back to the capacitor 22.

With this arrangement, it is not necessary for the control system to know the voltage inside the motor winding 29 or the relative position of the rotor. The generated current in the motor winding 29 can only go in one direction through the diodes 31 into the DC buss and only while the winding voltage is greater than that of the DC buss 17.

It will be seen that, when a power failure is detected, the switches are actuated, under control of the motor controller 23, to ensure that the motor runs as a generator for the time of the power failure or until motor rundown.

The power developed by the motor/generator 21 is fed into the DC link buss 17 to maintain the power supply for the magnetic bearings 18. By drawing power from the motor 21, the rotor is electrically braked thereby taking potentially hazardous kinetic energy away from the rotor shaft. The power generated during the run down together with the power stored in the capacitor 22 maintains the power supply to the magnetic bearings 18 and the controllers 23 and 24 for sufficient time to enable the motor 21 and associated rotating parts to run down to a stop.

Figure 3 showns the control algorithm of a program of the supervisory controlled 26 of the system of Figures 1 and 2. The program commences at box 32 ("power failure detected") where the power failure is detected either by power monitor 27 or by detecting a voltage drop across the capacitor 22. At this point the switches 28 are open and the motor acts as a generator (generator mode box 33) and existing current in motor winding 29 flows to the buss 17 through relevant diodes 31. Program box 34 involves controlling the switches 28 (IBGT's) to feed current back to the buss 17 and boost buss voltage. The swithes 28 are opened when this current reversal occurs (box 35). As soon as the buss voltage again drops switches SW1 and SW3 or SW2 and SW4 are closed (box 36) to short circuit the motor winding 29. If the winding current is "higher than a pre-set value" (box 37) the program moves to the exit box 40. If the winding current is not higher than the pre-set value the program moves to box 38 which causes switches SW1 and SW3 or SW2 and SW4 (whichever pair was previously turned on) to open. The next decision point is box 39 where the voltage rise across the buss is monitored and if the voltage rises above a pre-set value the program is then exited via box 40. If the voltage rise is less than the pre-set value the program reverts to box 36 and repeats the procedure.

In one particular form of the invention, when the electric motor is used to drive a refrigeration compressor, the supervisory computer, on sensing a power failure, will also operate to unload the compressor.

Subject to the motor speed, the inertia of the rotating parts associated with the motor and any external load on the motor, a run down time of between 2 to 3 seconds is achievable. By operating the motor 21 as a generator and supplying power to the DC link buss 17, the charge in the capacitor 22 is able to be maintained for all of the run down time. By maintaining a power supply to the magnetic bearings during run down, damage to the bearings is avoided and the motor is able to be safely brought to rest.

CLAIMS

1. A power control system for an electric motor having at least one magnetic bearing, said system comprising a DC/DC converter supplied from a DC link buss connected to a main power supply, said buss supplying power for the electric motor and for a bearing actuator, said converter providing low voltage DC power supplies for a motor controller, a bearing controller and a supervisory controller, the supervisory controller monitoring the main power supply and communicating with the motor controller and bearing controller so as to cause the motor to operate as a generator in the event of a failure of the main power supply to thereby supply power to the DC link buss to maintain operation of the magnetic bearing characterised in that, circuit switching components are connected to the motor winding and selectively switched in a manner causing current generated in the motor winding to flow in one direction into said DC link buss only while the winding voltage is greater than that of the DC link buss.

2. A power control system as defined in claim 2, characterised in that, said circuit switching components comprise first and second switches connected between a first end of the motor winding and the positive and negative sides of said DC link bus, respectively, and third and fourth switches connected between a second end of the motor winding and the positive and negative sides of said D C link bus, respectively, and a parallel diode connected across each switch to oppose the normal motor current flow.

3. A power control system as defined in claim 2, characterized in that, either said first and third or second and fourth switches are turned on to generate said current in said motor winding and immediately said current is generated said switches are turned off whereby the winding voltage rises above said buss voltage and said current flows into said DC link buss.

4. A power control system as defined in claim 3, characterised in that, said switches are IGBT's which are opened when a power failure is detected such

that existing motor current flows through relevant said diodes and into said DC link buss to boost the buss voltage, and when said buss voltage again drops either said first and third, or said second and fourth switches are slosed to short circuit said motor winding and immediately initiate current flow therethrough, whereupon said switches are opened causing the winding voltage to rise above the buss voltage and the generated current is fed back to said link buss.

5. A power control system as defined in claim 4, characterised in that, a capacitor is connected between the positive and negative sides of said link bus to store power fed back from said winding for motor run down.

6. A method of running down a high speed DC electric motor run on magnetic bearings in the event of a failure of the main power supply, said method including the steps of supplying the motor and the magnetic bearings from a high voltage DC buss connected to the main power supply, providing a DC/DC converter to supply low voltage DC power to a magnetic bearing controller and to a motor controller, using switching devices to control the motor operation, sensing a failure of said main power supply and providing a signal to the motor controller, characterized in that, said switching devices are selectively controlled on sensing said failure, to initially feed existing motor current to said buss, detecting when said buss voltage drops below a predetermined value and shorting said motor winding, and as soon as current flow in said winding commences, as a result of the short, removing said short whereby the winding voltage rises to above the buss voltage, feeding the resulting generated current back to said buss, and repeating said selective control as necessary until said motor is run down.

7. A method according to claim 6, characterized in that, a capacitor is provided across said buss to provide a buffer of stored power for said motor run down.

8. A method according to claim 6, characterized in that said step of detecting when said buss voltage drops below a predetermined value is achieved

by detecting a reversal of the current being fed to said buss.

9. A method according to claim 7, characterized in that, said switching devices comprise IGBT switches connected between each end of the motor winding and the positive and negative side of said buss respectively, and a diode connected in parallel with each switch, said diodes enabling said motor to act as a generator and feed current into said buss to assist said capacitor in maintaining the buss voltage until said motor is run down.

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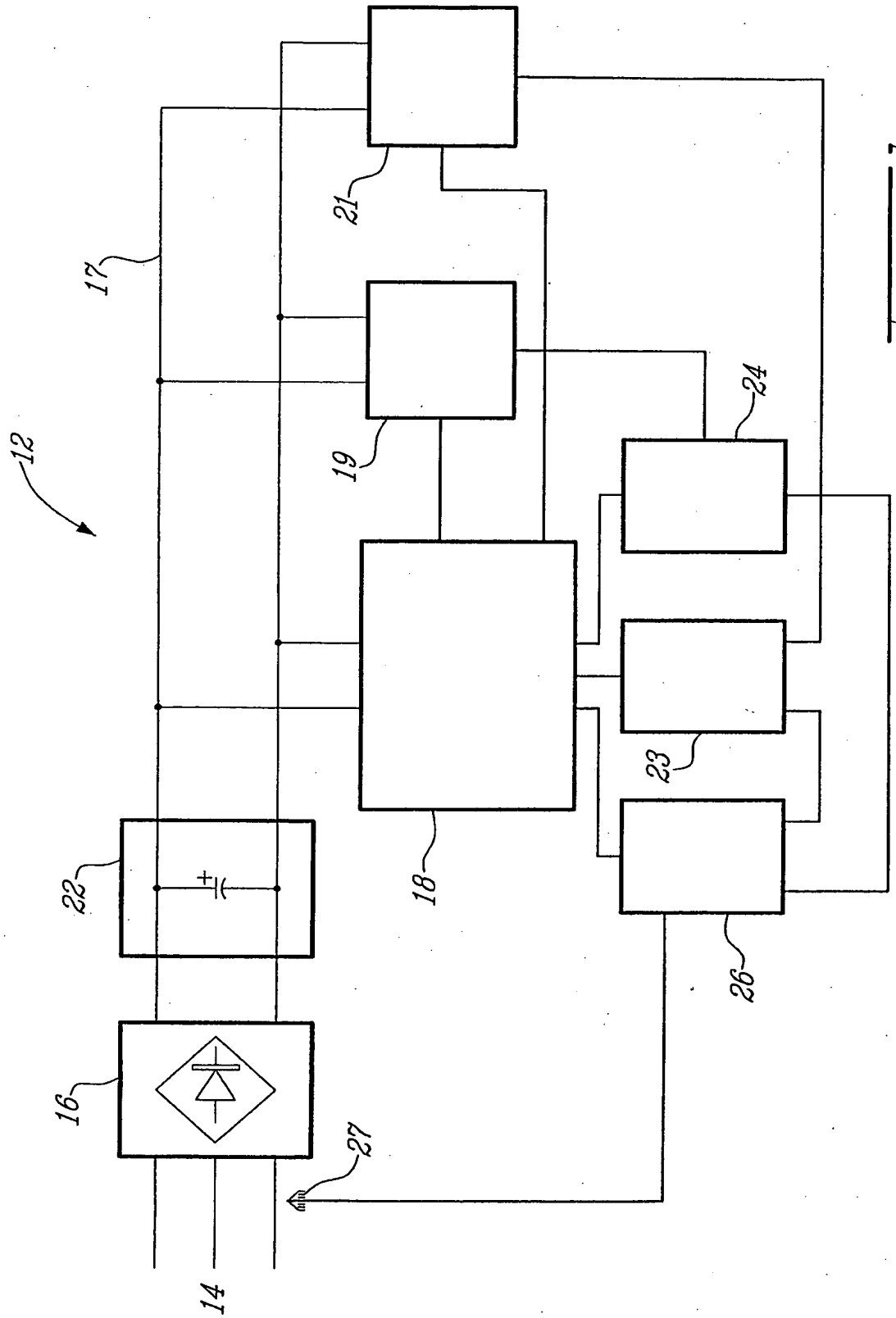

FIG. 1

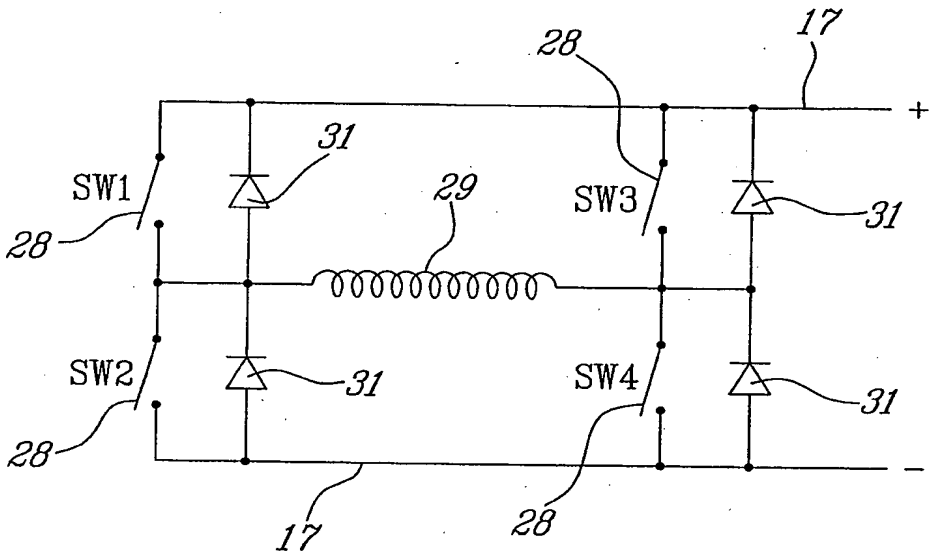

Fig. 2

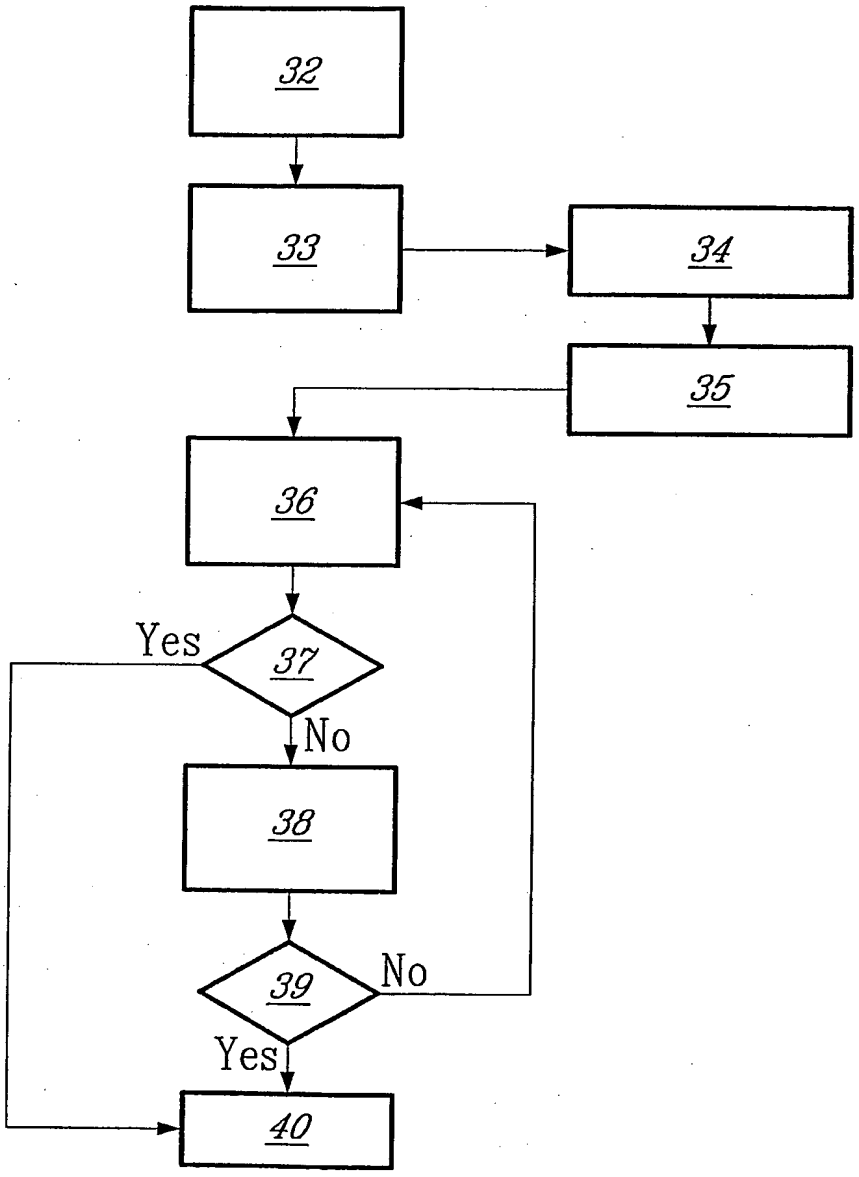

Fig. 3

INTERNATIONAL SEARCH REPORT

Application No
PCT/CA 03/01454

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02P6/24 H02J9/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02P H02J H02K H02M F16C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 0 825 702 A (SULZER ELECTRONICS AG ;LUST ANTRIEBSTECHNIK GMBH (DE)) 25 February 1998 (1998-02-25) column 1, line 3 -column 4, line 3; figure 1	1-9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
19 December 2003	05/01/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Braccini, R

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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